CHAPTER 2. THE RADIO FREQUENCY (RF) SPECTRUM

200. RF SPECTRUM. The RF or electromagnetic spectrum is a finite natural resource used by every country in the world. The internationally used frequency unit is the "Hertz," named for an early pioneer in spectrum research. The Hertz (Hz) is defined as one cycle per second (cps), with further prefixes from the Greek to indicate multipliers. One thousand Hz is defined as 1 kiloHertz (kHz), one million Hz is 1 MegaHertz (MHz) and one billion Hz is 1 GigaHertz (GHz), etc. The electromagnetic spectrum emissions of interest, which are called the radio frequency bands, begin at 10 kHz and end at 300 GHz. Above 300 GHz are visible light, X-rays, gamma rays and other electromagnetic phenomena.

201. MAKEUP OF THE SPECTRUM.

a. By international agreement, the radio spectrum is divided into major bands in frequency decimal multiples of three. The radio spectrum was originally defined in terms of metric system wavelengths. The three multiple came into use because the speed of light and electromagnetic propagation is about 300 million meters per second in free space. The length of a full wavelength is 3×10^8 meters per second (m/s) divided by the frequency in Hz. Noting this frequency/wavelength relationship, a frequency of 3 MHz calculates to 100 meters for a full wavelength.

b. These decade bands of frequencies have international defined names, using common terms. For example, the band of frequencies from 30 kHz to 300 kHz is named Low Frequency (LF) and 300 kHz to 3 MHz is designated Medium Frequency (MF). The bands continue from LF and MF to High (HF), Very High (VHF), Ultra High (UHF) and Super High (SHF) with continuations above and below these ranges. The frequency band names are divided by decimal breaks defined in wavelengths; e.g., 300 kHz is 1000 meters, 3,000 kHz is 100 meters, etc. The United States uses frequency in Hz as the unit for specific administrative tracking of spectrum assignments.

202. SPECTRUM LIMITATION CONSIDERATIONS.

a. Aeronautical safety systems shall be accommodated in aeronautical spectrum which is specifically allocated for the service being satisfied and which is used exclusively by aeronautical safety systems. This ensures protection from non-aeronautical users so that the high levels of integrity and availability required by civil aviation can be met.

b. Congestion within the available spectrum is not the only factor limiting its use. First and primarily are the international agreements and treaties to which the United States is a signatory. These matters are covered in detail in chapter 3. Second is the necessary frequency bandwidth required to convey the transmitted information. Other considerations are spectrum efficiency, propagation, capacity, equipment, economics and interference.

c. International agreements divide the spectrum into bands for either exclusive or shared use by a specific service. The aeronautical service is just one of many defined services which have allocations in specific and limited bands. The aeronautical mobile (R) and aeronautical radionavigation services are directly related to safety of life and property in the air. Therefore, most such bands are allocated exclusively worldwide, where the operations deal directly with operation of aircraft. Ancillary aeronautical services, such as fixed microwave point-to-point systems, are shared with other users.

d. Aeronautical service frequency bands are distributed throughout the radio spectrum.

e. Propagation characteristics play a major role in the limitations on use of the assigned spectrum. LF and MF operate primarily on groundwave and can cover hundreds or thousands of miles day or night quite reliably. HF uses the ionosphere to reflect signals for great distances around the earth, but are greatly affected by day-to-night and seasonal changes. Beginning around the VHF band, "radio line-of-sight" (RLOS) propagation conditions exist. RLOS extends the visual line-of-sight distance by virtue of the phenomenon that radio waves "bend" near large objects such as the earth. See the appendix, Technical Data for VHF/UHF Communications Frequency Engineering, for details. At VHF frequencies and above, radio signals travel in a straight line, modified by the bending of the path due to the RLOS effect. Large metallic or electrically-conducting objects such as steel buildings will attenuate, retard or deflect the signal's path. Signal reflection occurs under some conditions, but it is not considered as a reliable path except where the reflector is a part of the planned path.

f. Technical equipment, particularly its changing style as the state-of-the-art progresses, places severe restrictions on the spectrum engineer in engineering frequencies. For example, the original channel assignments in the VHF communications band were every 200 kHz on the odd frequencies between 118.1 and 126.9 MHz, e.g., 118.1, 118.3, etc. Congestion required narrowing the channels to 100 kHz so frequencies could then be assigned on every decimal frequency, 118.1. 118.2, etc. While technically the number of channels doubled per MHz, all could not be used simply. There were still thousands of 200 kHz channeled transceivers in use. It took years of education and finally agency orders to permit the spectrum engineer full use of the 100 kHz channels. Subsequent congestion brought further reduction to 50 kHz, then currently to 25 kHz channels, yet protection for a "grandfather" period for older operating equipment always must be given.

g. Economics also has a very big impact on the spectrum engineer's ability to engineer frequencies. As described in subparagraph e, even though revised frequency engineering allocations establishes additional channels, they may not necessarily be able to be used. Whether airline or a private aircraft owner, the ability to meet all the requirements for new equipment to meet technological advances is limited by the ability to pay for it.

h. Interference can be defined as any undesired signal or energy which prohibits or degrades the normal reception of the desired signal. It can be divided into three broad categories; adjacent channel or cochannel radio sources, man-made electrical noise and natural solar and atmospheric noise.

(1) Adjacent channel or cochannel interference is caused by undesired radio transmissions which the receiving device is unable to separate from the desired transmission. Adjacent channel interference is caused by emitters using nearby channels and occurs because of the inability of the pass band of the victim receiver to discriminate against near-frequency signals.

Cochannel interference is caused by emitters using the same frequency which are too close geographically. Proven radio frequency spectrum engineering criteria are used by the spectrum engineer to establish an interference-free assigned frequency.

(2) Man-made interference is the most common and most insidious. The sources are limitless, from "plastic welders," to electric motors of all types, to the incidental and spurious radiation of other transmitters. In addition, there are cases of intentional interference, so-called "bogus" or "phantom" controllers, which FAA must investigate (and prosecute) with the help of other agencies.

(3) Solar and atmospheric noise are outside human control. The sun emits an enormous amount of energy throughout the spectrum, varying in day-to-day intensity and frequency. In frequencies through VHF, solar radiation and atmospheric noise such as lightning and precipitation static are significant. From UHF and above, noise generated internally in equipment is the controlling factor.

(4) Intermodulation is defined as the presence of unwanted signals at the output of a less-than-ideal amplifier resulting from modulation of the components of a complex waveform by each other in a nonlinear system. When two or more signals are applied to a nonlinear device, a mixing or intermodulation action results and signals are produced, having frequencies equal to the sums and differences of the original input signals, among other signals. An otherwise linear device may be driven into nonlinear operation in the presence of strong external signal levels. Although most cases occur in receivers, problems do occur when two or more transmitters start radiating a mixed frequency created when a mix occurs in their final amplifiers, particularly when their antennas are in close proximity. Detailed information will be found in the appendix.

(5) Desensitization is the deterioration of reception of a desired signal due to the proximity of a very strong signal. The source of the problem could be of any frequency theoretically, but in practice, communications frequencies usually are effected only by very strong signals below about 1 GHz. The strong signal drives the receiver into non-linear function, desensitizing normal reception as well as generating many unwanted spurious signals within the receiver.

203. thru 299. RESERVED.